1. INTRODUCTION

The term Manufacturing Execution Systems (MES) was created by Advanced Manufacturing Research (AMR)[1] in 1990. This term describes systems that enable the execution of manufacturing, through the integration of the planning and control systems of an enterprise:

"Middle-level information systems, known as Manufacturing Execution Systems (MES), bridge the critical information gap between upstream, transaction-oriented, planning activities and downstream, event-oriented execution activities."
(Digital Basestar, 1998:www.asia-pacific.digital.com/info/manufacturing/integr.htm)

According to MacDonald (1998:*www.consilium.com/Publications/roi.htm*) the evolution of MES started long before the term was coined in 1990, and it is still evolving:
"An MES is not something new or something only large, complex manufacturers need. If you have a manufacturing plant, you already have an MES"

CONTENTS OF THIS CHAPTER

1
AMR Research is an industry and market analysis firm specializing in enterprise applications and related trends and technologies. Tracking more than 400 leading software and service providers, AMR Research helps Global 1000 companies evaluate, select, and manage new systems for every part of the enterprise, including logistics and supply-chain management, Enterprise Resource Planning (ERP), Manufacturing Execution Systems (MES), and electronic/Internet commerce. (www.amrresearch.com)

1. 1. PROBLEM STATEMENT

A project was launched at the beginning of 1998 as a joint effort between CSM Systems and the Departments of Industrial and Systems Engineering and Computer Science (University of Pretoria). The purpose of this project was to develop an interface between a specific Enterprise Resource Planning (ERP) system (SAP) and a shop floor control system (DIAMES). Through this project the project members discovered the existence of the term MES. Further research brought forward the following categories of issues:

1. MES definitions and business models.
2. MES and the Industrial Engineer.
3. The need for MES awareness and education in South Africa.
4. Developments concerning the original project.

1. 1.1. MES DEFINITIONS AND BUSINESS MODELS

Numerous definitions for MES exist. However, MES definitions, concepts and models still evolve. In October 1998 AMR Research published a completely new model - the REPAC model - to replace the original MES model developed by them less than a decade before. This rapid evolution is to a great extent the result of the evolution of related manufacturing strategy and information technology. The consequences of these rapid changes are the following:

- MES theories and models are changing faster than the rate by which users and potential users are educated.
- Software developers and integrators often abuse the term MES for marketing purposes. Products are often promoted as total MES solutions, while the product only provides partial integration.
- Although underlying technology, strategy and theory are ever changing, the concept of a system that enables the execution of manufacturing, is becoming more and more accepted, throughout manufacturing industries.

1. 1.2. MES AND THE INDUSTRIAL ENGINEER

The concepts associated with the definition of MES (MRP, MRPII, systems integration, shop floor control etc) are associated with (amongst others) Industrial Engineering. During the past four years a total of five articles appeared in the International Industrial Engineering journal, (IIE Solutions), with titles containing the term MES. Approximately ten more articles, which refer to MES in some way or another, appeared in this journal. The assumption is made from this that the Industrial Engineer is concerned with the use/ development/ integration of MES to some extent.

1. 1.3. THE NEED FOR MES AWARENESS AND EDUCATION IN SOUTH AFRICA

As part of a resent survey by South African Instrumentation and Control (1999:8-12), thirty software integrating companies in South Africa were given the choice of highlighting (using five terms) their integration expertise. Nine of these thirty companies choose MES as one of these five terms. Representatives from all of these companies were asked via e-mail to comment on MES in South Africa. From the response the conclusion was made the opinions on the nature, scope and applications of MES varies.

The need to educate South African Industries with regard to MES is identified from interviews with two of the leading MES integrators in South Africa.

1. 1.4. DEVELOPMENTS CONCERNING THE ORIGINAL PROJECT

Since the original project was launched the scope and direction were changed due to several developments:

- The development of a unique interface between the specific shop floor control system and ERP system mentioned earlier proved to be infeasible.
- The need was identified to determine the position of DIAMES in the industry market and to consider the feasibility of developing it into a comprehensive MES product. This need is currently attended to through a separate project.

The term MES is well accepted by South African manufacturing industries. Together with underlying technologies and manufacturing strategies, these systems are evolving at a rapid rate. The Industrial Engineer has a role to play regarding the coordination of this evolution.

1. 2. RESEARCH PURPOSE AND LIMITATIONS

The purpose of this dissertation is to determine and establish the role of Industrial Engineering in the development, implementation and use of MES.

1. 2.1. LIMITATIONS

The following boundaries are drawn for purposes of this dissertation:

- The term *Manufacturing Execution Systems*, implies that it is a concept focussed on the manufacturing industry. MES principles and products can, presumably be applied equally to the service industry. For purposes of this dissertation only the manufacturing industry is considered.
- Although trends regarding information technology are investigated, a detail study of underlying information technology, related to MES, does not fall within the scope of this dissertation. This study is conducted from the viewpoint of the Industrial Engineer. Although the role of the IT analyst in the development op MES is acknowledged, it fell outside the scope of this dissertation.
- All interviews are conducted with *South African* Industrialists. Whilst international literature is used to seed the study, the conclusions and recommendations are limited to the South African manufacturing environment.

1. 3. RESEARCH STRATEGY, STRUCTURE AND CONTRIBUTION

To meet the purpose of this dissertation, the following research question and related key questions have to be answered:

Why should the Industrial Engineer be concerned with MES?
• What are MES? • What is an Industrial Engineer? • How does Industrial Engineering relate to MES?

Within the boundaries (as set in the previous section), two propositions are made. Several objectives are defined to support these propositions. Questions that have to be answered to meet the objectives are compiled accordingly.

PROPOSITION 1: The concept of MES is valid. (It is used by and useful to manufacturing industry.)	
Objectives	**Questions**
Integrate literature regarding MES business models and applications.	• What are Manufacturing Execution Systems? • Where does the concept of MES originate from and in which direction is it evolving? • In which industry sectors (and to which extent and with how much success) are MES implemented?
Integrate opinions of South African role players throughout the literature study	• To which extent is the concept of MES accepted by South African manufacturing industry? • What are the view of South African developers, integrators and users?
Develop a new or combined model – if current models prove to be insufficient.	• Can current MES function models be used as tool to evaluate MES products and environments? • What should the elements of an appropriate model be?
Demonstrate the validity of the newly developed MES model – as well as the validity of MES as concept – through a case study (DIAMES).	• How does DIAMES perform as a Manufacturing Execution System and what developments are required? • In which other ways can this model be used to analyze MES products and environments?

PROPOSITION 2: The Industrial Engineer has a contribution to make, regarding MES	
Objectives	**Questions**
Relate MES to Industrial Engineering by integration literature on Industrial Engineering.	• How are Industrial Engineers trained? • How are Industrial Engineers practically involved in industry? • Which roles are to be played in the MES arena and to which extent can Industrial Engineers fulfill these roles?
Initiate a research program for a research program for MES at the Department of Industrial and Systems Engineering (University of Pretoria).	• What other MES research initiatives exist? • What should be the focus and scope of such an initiative?

1. 3.1. CONTRIBUTIONS MADE THROUGH THIS RESEARCH

Through this dissertation, the following contributions are made, towards MES research:

- Current models and theories are evaluated, integrated and presented in a way that can be used as basis for further research on MES.
- A new model – to be used as MES evaluation tool – is developed and demonstrated.
- The role of the Industrial Engineer, regarding MES, is evaluated and explained.
- The foundation is laid for an MES research initiative at the Department of Industrial and Systems Engineering (University of Pretoria).

1. 3.2. STRUCTURE AND SCOPE

The questions asked to meet the objectives are answered in this dissertation, according to the structure of *Table 1*.

Table 1

The scope of this dissertation

GOAL	PROPOSITION 1 The concept of MES is valid	PROPOSITION 2 The Industrial Engineer has a contribution to make, regarding MES
Business Position	What are Manufacturing Execution Systems?	How are Industrial Engineers trained? How are Industrial Engineers practically involved in industry?
History	Where does the concept of MES originate and in which direction is it evolving?	What is an Industrial Engineer?
MES Functions and the development of MES Function Matrix	Can current MES function models be used as tool to evaluate MES products and environments? How should an appropriate evaluation model look?	Which of the MES functions are the concern of the Industrial and Systems Engineer?
Case Study	Does an evaluation exercise - using the newly development MES model - prove that the product DIAMES can indeed be marketed as a manufacturing execution system?	
MES Role Players: Developers	What is the view of South African developers? What is the role played by an MES developer?	To which extent can the Industrial Engineer fulfill the roles of developer?
MES Role Players: Integrators	What is the view of South African integrator? What is the role played by an MES integrator?	to which extent can the Industrial Engineer fulfill the role of integrator?
MES Role Players: Research	Which research initiatives, regarding MES, exists?	To which extent can the Industrial Engineer fulfill the role of researcher? What should the focus and scope be of an MES research initiative at the Dept. of Industrial Engineering (University of Pretoria)?
MES Role Players: User	In which industry sectors (and to which extent and with how much success) are MES implemented? To which extent is the concept of MES accepted by South African manufacturing industry?	What should the focus and scope be of such an initiative?

1. 4. RESEARCH METHODOLOGY

To conduct the research, MES information was *gathered* and *applied*.

1. 4.1. GATHERING OF INFORMATION

An extensive literature study (including interviews with industry experts) needs to be conducted. Through the literature study as much as possible information and opinions regarding MES – and related concepts - are integrated. Literature is studied to make it possible to position MES within a South African and Industrial Engineering context and to identify further areas of research where gaps or contrasting opinions exist. Where these gaps are identified, models and theories are combined or modified and ultimately evaluated against the case study.

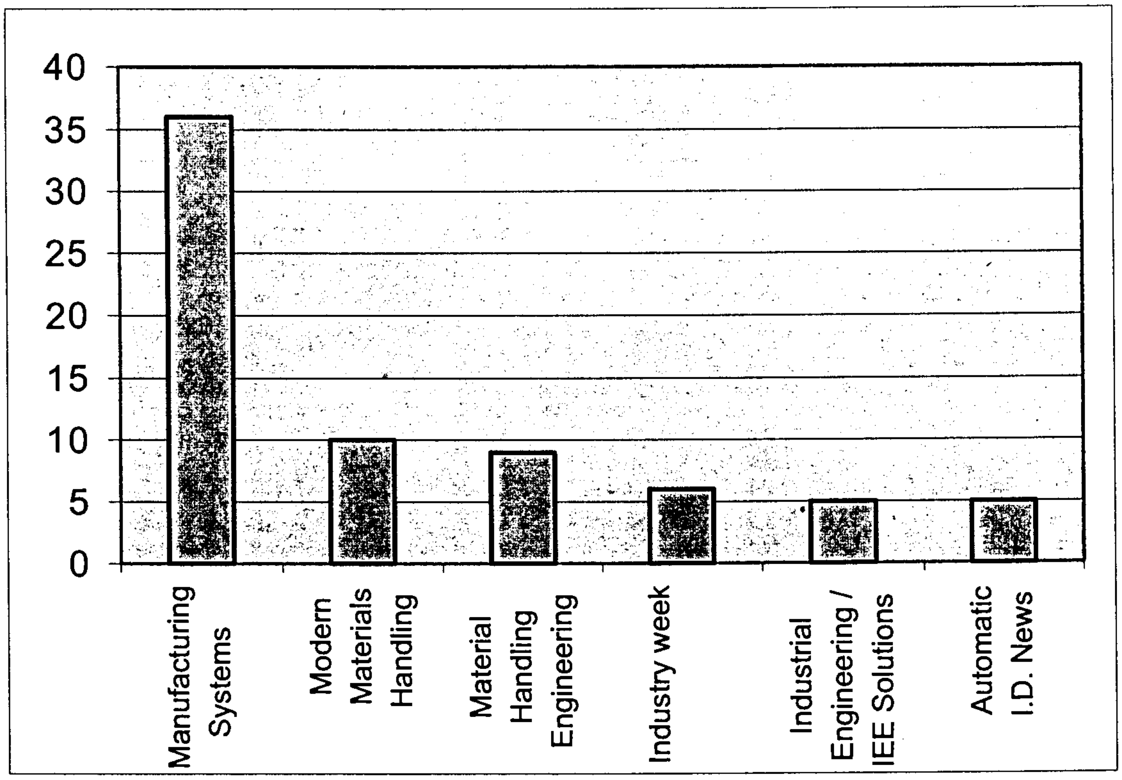
Information for this study is gathered from publications in textbooks, journals, publications on the World Wide Web as well as interviews and discussions with relevant MES developers and integrators from industry.

(a) INFORMATION GATHERING THROUGH PUBLICATIONS IN JOURNALS

References to 106 journal articles on Manufacturing Execution Systems, published before 1999 were identified. The first article appeared in 1991 (1 year after the term was coined). In the next year 16 articles were published and in 1993 the number of articles was 14. The largest number of articles was published in 1995 and 1996 (20 and 22 respectively). In 1997 sixteen MES articles appeared and in 1998 thirteen. Information on the journals in which these articles appeared is provided in *Figure 1* (on the following page).

Figure 1

Number of MES articles published in specific journals



All of these journals are concerned with business and manufacturing processes, rather than information technology. This is due to the fact that this research is not conducted from the viewpoint of an IT analyst. As noted earlier, the number of articles from IIE Solutions (the International Industrial Engineering Journal) implies a link between Industrial Engineering and MES, which is worth investigating.

(a) INFORMATION GATHERING THROUGH PUBLICATIONS IN BOOKS

Several information and operations management books were consulted. Information NOT given was of equal value than information given. The term Manufacturing Execution Systems has not been used in any of these books (publication dated varied from 1989 to 1997). Although the term MES is not used, MES functions – as identified by writers of journals and internet articles – are described in most of the books. Only one book was found, which focuses on MES: “Applying Manufacturing Execution Systems” (McClellan,1997).

The conclusion can be made from this that the concept of MES is an insignificant concept and do not deserve any attention. However, the wide acceptance of this term – as can be derived from publications in journals and the World Wide Web, as well as interviews – can not be ignored. The absence of literature on MES in books is, rather, considered as a signal that more research needs to be done.

(c) INFORMATION GATHERING THROUGH WORLD WIDE WEB (WWW)

The information gathered from the World Wide Web can broadly be categorized as either academic publications or promotional material.

- Academic material refers to articles, which are – apart from being published on the World Wide Web – published in official journals or course material. Publications from official research institutes are also considered as academic material. The integrity of this information is contemplated equal to information gathered from traditional publications in journals.
- MES developers and integrators provide promotional information to market their product or service. Due to the subjective nature of this information, this information is primarily used to identify trends.

(d) INFORMATION GATHERING THROUGH INTERVIEWS AND SURVEYS

An initial survey was conducted to determine the need for further research on MES in South Africa. The survey was directed – via e-mail – to South African research institutes, universities and software integrators MES. The focus was on the integrators and researchers of MES - rather than the users and potential users. This was done due to the necessity that respondents had prior knowledge regarding MES. The additional information and requests provided by the respondents was of greater importance than the statistical data obtained from answers. The positive reaction to the survey was a definite indication that there is a need to research MES in South Africa.
Interviews were conducted with representatives of companies concerned with the integration of Manufacturing Execution Systems. The outputs from these interviews are integrated throughout this report. Information from brochures of these companies is also used. The names of people interviewed and their involvement with MES are listed in *Table 2* (on the following page).

Table 2

Interviews held with persons from industry involved with MES

Schalk Claassen (Schalk_Claassen@voltex.co.za)	CSM Systems, representing DIAMES	February 1998 June 1998 January 1999 March 1999
Neville Searle	President of the South African MES Special Interest Group.	October 1998 April 1999
Kevin Archer	Director of Automated Systems Engineering Technologies and Member of the MES Special Interest Group	October 1998
André Brits ab3@isis.co.za	Account Executive of KEOPS ISIS	November 1998 April 1999 May 1999
Pieter Theron lt@isis.co.za	Project Manager at KEOPS ISIS	October 1998 November 1998 April 1999 May 1999
Henno Marais (chmarais@icon.co.za)	Webmaster and member of the South African MES Special Interest Group.	

1. 4.2. APPLYING INFORMATION

(a) DEVELOPMENT OF AN MES FUNCTION MATRIX

Based on information gathered, the need was identified to develop a new MES function model. This need is attended to through the development of an MES Function Matrix:

- Principles of value management are used to develop this matrix.
- The matrix is evaluated against criteria derived from criticism against existing models.
- The MES Function Matrix is validated through current function definitions.
- Possible applications of this matrix are discussed and some of these applications are illustrated throughout the dissertation.

(b) INITIATION OF A RESEARCH PROGRAM FOR MES

The following steps was followed to initiate a research program for MES at the Department of Industrial and Systems Engineering (University of Pretoria).

- Current institutes, which embark on MES research, were investigated.
- The extent to which an MES research program can contributes towards the missions of the Department of Industrial and Systems Engineering and University of Pretoria was evaluated.
- A mission statement for this initiative was compiled.
- A web site for this initiative was created.

(c) CASE STUDY

An independent project is conducted concurrent to this dissertation to evaluate DIAMES as an MES product. Relevant results from this project are presented, modified and expanded upon chapter 5.

(d) DISSERTATION DOCUMENT

Background on the position of MES within the business and the evolution of MES are given in Chapters 2 and 3, respectively. The need for a new MES function model is motivated and the development of the new model is explained in Chapter 4. The independent investigation on DIAMES and the development of the alternative model are integrated in Chapter 5. In the remainder of this dissertation the Industrial Engineer is evaluated with respect to the roles played in the MES arena. Chapter 6 is used to evaluate the roles of developer and integrator. The users of MES user are investigated in Chapter 7 and MES research initiatives are evaluated in Chapter 8. In Chapter 9 the research for purpose of this dissertation is concluded and evaluated regarding the goals set in this introductory chapter.

2. THE POSISION OF MES WITHIN THE BUSINESS

"Manufacturing Execution Systems (MES), are information systems that reside on the plant floor, between the planning system in offices and direct industrial controls at the process itself." (AMR Research: www.amrresearch.com*)*

MES functions, applications and concepts existed before the term was created and has also evolved since 1990. In this chapter current MES business models - established before and after 1990 - are evaluated.

CONTENTS OF THIS CHAPTER

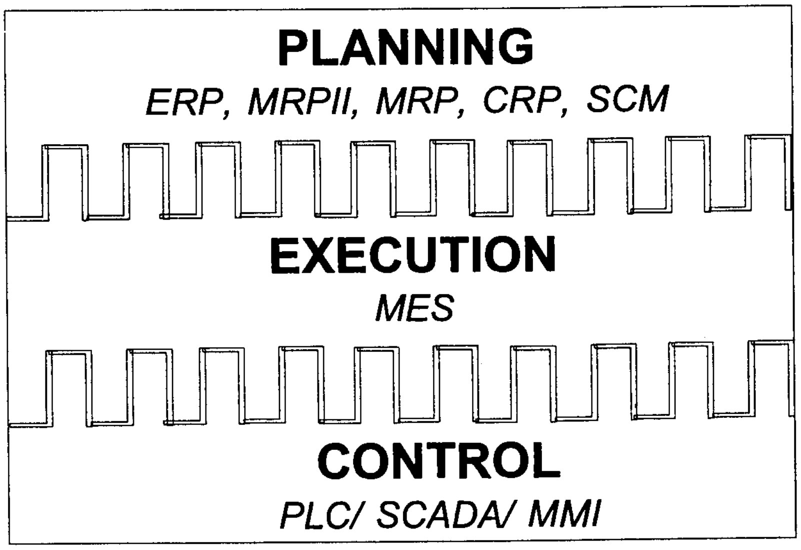
2. 1. CURRENT MES BUSINESS MODELS

AMR Research developed a simple model to explain the position of Manufacturing Execution Systems within a business (*Figure 2* on the following page). This model - called the Three-Layer-Model is used in the majority of MES literature. According to this model the three main activities within a business are related to three groups of information systems:

- The top layer comprises of systems such as Enterprise Resource Planning (ERP), Manufacturing Resource Planning (MRPII), Material Requirements Planning (MRP), Capacity Requirements Planning (CRP) and Supply Chain Management (SCM). Plans are send down in batch mode to the execution layer. Information on how the plans are executed is received from the execution layer.
- The execution layer acts as link between the control and planning layers. Communication between the execution and control layers occurs in real-time.
- Control is established through devices and systems such as programmable logic controllers (PLC), Supervisory Control and Data Acquisition (SCADA) and Man Machine Interfaces (MMI). Information from these devises is sent in real-time to execution layer. Work, process and maintenance instructions are sent back.

Figure 2

Three- Layer -Model by AMR Research



The statement was made that this business model is widely accepted. This is supported by the fact that MESA International[1] has not made any significant changes to this model. The model is only expanded: the types of systems within these layers - and its interfaces with MES – are modeled more specifically (as indicated in *Figure 3* on the following page).

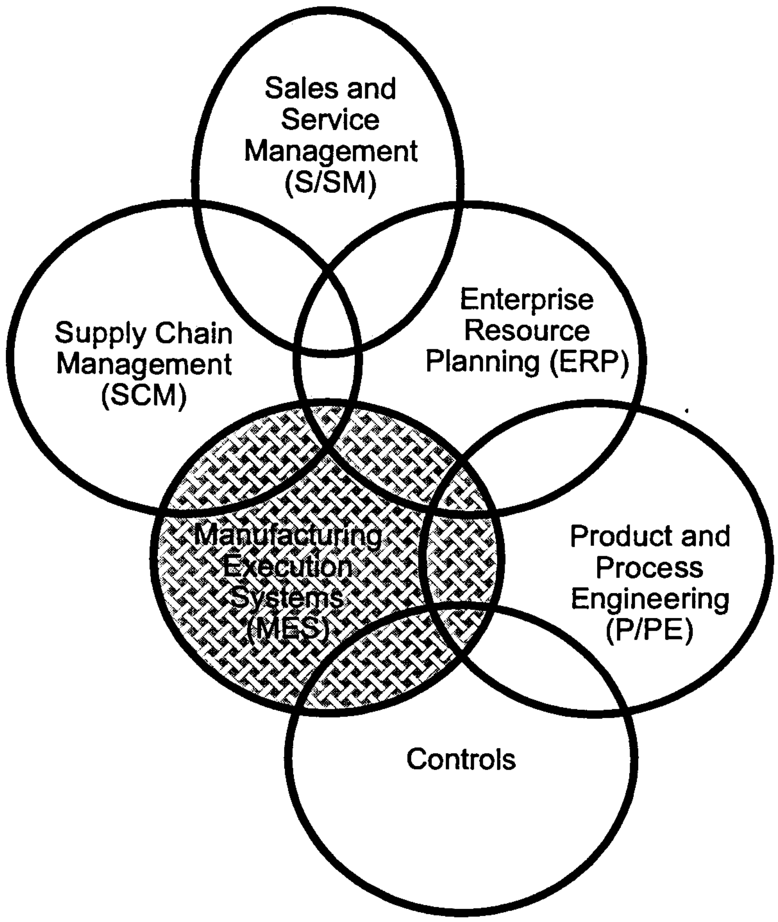
- Scheduling may be a component of both Manufacturing Execution Systems (MES) and Supply Chain Management (SCM).
- Labour management may appear in MES, Sales & service Management (SSM), and the Human Resource (HR) function of Enterprise Resource Planning (ERP).
- Document control can be a function of MES and Product and Process Engineering (P/PE). Both MES and Control can include process management. Degrees of overlap vary from industry to industry.

1
MESA International (Manufacturing Execution Systems Association) is a not-for-profit trade association providing a legal forum for competitors to work together to expand awareness and use of manufacturing technology, particularly MES and all the related products and services required by the modern manufacturing enterprise. (www.MESA.org)

Figure 3

The MES Context model by MESA International

(MESA International,1998:www.MESA.org/html/main.cgi?sub=5)



MESA International also uses the Three-Layer-Model to develop a model, which illustrates the flow of data to and from the execution layer. This is discussed in the next section.

2. 2. DATAFLOW BETWEEN MES AND NEIGHBOURING SYSTEMS

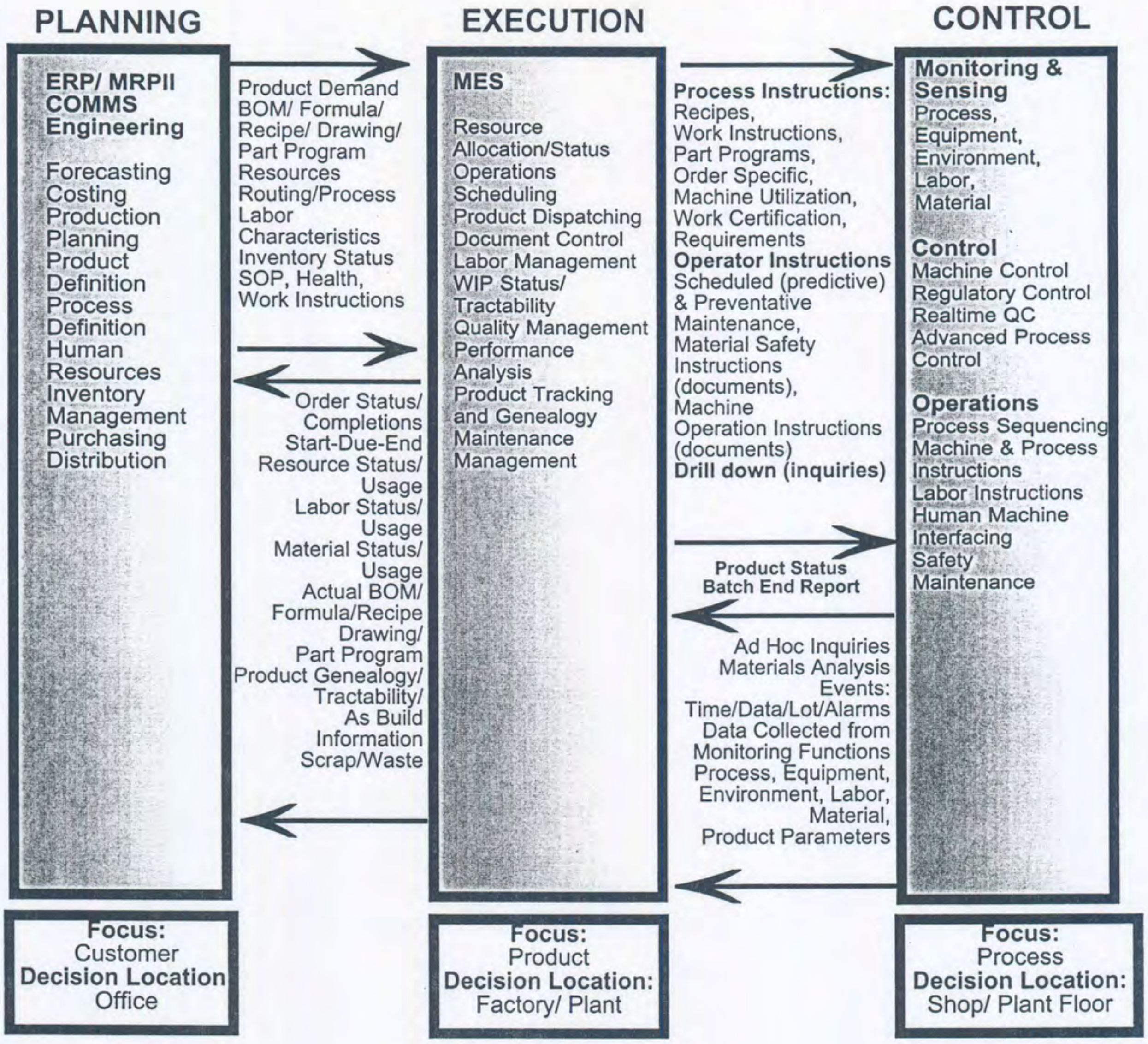
"The word "integration" is one of the most overused, abused, and misunderstood buzzwords in the lexicon of application software."

Luber (1991:298) made this statement with regard to Manufacturing Resource Planning (MRPII) systems. It is, however, just as applicable to MES. The difference between interface and integration is very much related to the underlying information technology. This is discussed at the end of this chapter. However, it is not an objective of this dissertation to define the difference between interface and integration. When the data flow between MES and neighboring systems is explained, the assumption is made that this data flow is established either by integration or through an interface.

The data flow model in *Figure 4* (on the next page) was developed by MESA International (1998:www.MESA.org/html/main.cgi?sub=5). This model is an expansion of the Three-Layer-Model of AMR Research. Although the layers are vertically orientated on this models, the way in which these layers interacts remains the same. Arrows indicate the data flowing to and from each of these layers, while the transformation of data is indicated within the boundaries of each layer. The flow of data from/ to the control and planning layers is discussed respectively.

Figure 4

The flow of data between MES and planning and control systems



2. 2.1. DATA FLOW BETWEEN MES AND CONTROL SYSTEMS

"A Control System is defined as being 'responsible for measurement, monitoring, and manipulation of production, people, products, and processes' within the environment of the process or shop floor."

(MESA International,1998:www.MESA.org/html/main.cgi?sub=25).

According to the Object Management Group (1998:5), controls are usually hybrid hardware/software systems such as distributed control systems (DCS), programmable logic controllers (PLC), distributed numerical control (DNC), supervisory control and data acquisition (SCADA) systems designed to automate the way in which the product is being manufactured.

The focus of the control systems is on the process or operation itself.
The process is manipulated and rearranged by controls to assure

- that performance are kept within the defined tolerances,
- that continuous flow of material flow is maintained (as required by the process) and
- that resources is utilized optimally.

Inputs and output from and to the control layer can either be relayed and analyzed as they occur or stored in a database for later retrieval and analysis.

Forger (1997: http://www.manufacturing.net/magazine/mmh) explains technology - such as bar codes, radio frequency data communications, and radio frequency identification - is used to establish input and output to and from the control layer.

MESA International continues by explaining that the specific performance of a piece of equipment or person, is the concern of the control layer, rather than the execution layer. The results from these discrete operations are communicated to the execution system, after the results were converted together with process data.

The execution layer downloads instructions to the control layer. These instructions direct people and machines in the carrying out of the manufacturing operation. These resources monitor and control their own operations and act to comply with the requirements set out by the execution layer. This monitoring and control can include separate software and hardware products for quality, process control, data acquisition, safety and maintenance. Drill-down inquiries, or status indicators, from the execution layer can spontaneously access information created on an as-needed basis for process control. (MESA International,1995:www.MESA.org/html/main.cgi?sub=26)

2. 2.2. DATA FLOW OF MES WITH PLANNING SYSTEMS

The MES is the basic interface between planning and execution. Information is flowing bi-directionally. Factory floor information aids the office system (eg. ERP system) in job costing, payroll, lot control, inventory management and other factors on work actually being performed (and not the work planned to be performed).

According to MESA International (MESA International,1995: www.MESA.org/html/main.cgi?sub=26) the planning layer normally do not function in real-time, but rather in a batch mode. The planning layer notes product usage, customer orders, and materials requirements, and sends requests to the execution layer initiate the production of more, less or other products. The Manufacturing Execution System then perform the required transactions and send out the necessary instructions to enable the production of those products.

The Manufacturing Execution Systems often needs information, which not generally found in office and planning systems. Therefor, additional data elements are added to the Manufacturing Execution System the enable the organizing of manufacturing operations on a realistic basis. Based on this additional data, the Manufacturing Execution System send the appropriate data back to the planning systems to update material and capacity plans.

2. 3. THE REPAC MODEL

"In essence, the REPAC model takes the formal and informal systems in plants today and puts them in context. It has an eye to future systems that automate all plant activities. It is an extension of earlier models and it tracks the pragmatic way systems are implemented in factories today. More importantly, it identifies the holes in the architecture when using today's product categories."
(Swanton,1998: www.advmfg.com/repac*)*

AMR Research developed the REPAC model, by the end of 1998 as extension to the current Three-Layer-Model. In the remainder of this chapter the REPAC model is used to explain the interaction between MES and the supply chain. It is also demonstrated how the REPAC model can be used to contextualize business processes and systems currently used in businesses.

2. 3.1. THE RELATIONSHIP BETWEEN MES AND THE SUPPLY CHAIN

The expanding role of manufacturing information in the Total Supply Chain Management requires that MES evolve to easily integrate with enterprise systems. MES must also maintain the flexibility to provide customized integration for individual companies within different industries. The former dictates a set of off-the- shelf interfaces available to leading ERP suppliers. The latter entails a level of openness defined by accessibility to information via a broad range of application programming interfaces that facilitate customization.
*(Consilium,1998:*www.consilium.com/Publications/optv2n2/nexgen.htm*)*

The REPAC model is build upon the Supply Chain Operations Reference (SCOR) model (*Figure 5*) and is discussed as part of an attempt to place MES within context of the supply chain.

According to Hakason (1998:www.autoidnews.com), the SCOR-model (*Figure 5*) is based on four distinct management processes:

- plan,
- source,
- make and
- deliver

Each of these processes is explained in *Table 3*, following *Figure 5*.

Figure 5

The Supply Chain Operations Reference (SCOR) model

(Supply Chain Council:www.supply-chain.org/html/scor_overview.cfm)

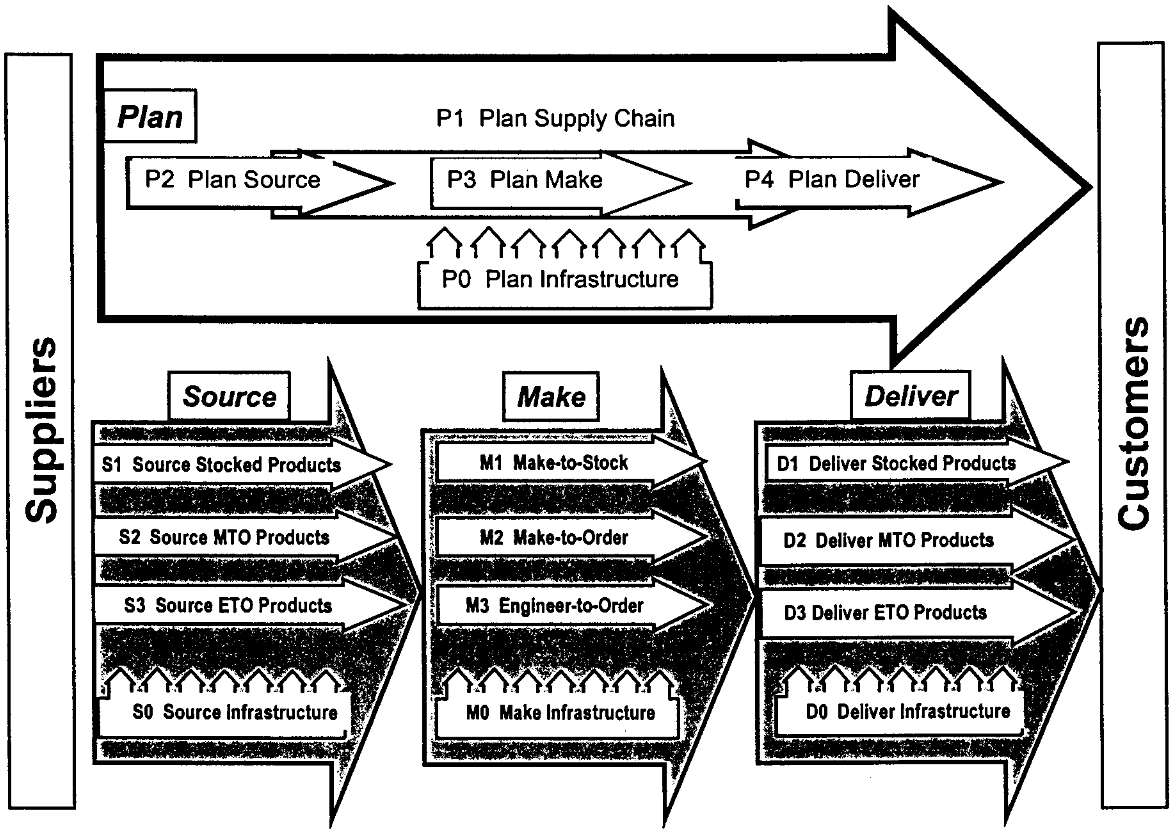


Table 3

Management processes within the SCOR model

Process	Description	Activities
Plan	Demand and supply planning and infrastructure management.	• Assess supply resources • Aggregate and prioritize demand requirements and plan - inventory - distribution requirements, - production, - material and rough-cut capacity for all products and all channels. • Manage infrastructure: - make/buy decisions, - supply chain configuration, - long-term capacity and resource planning, - business planning, - product phase- in/phase-out, manufacturing ramp-up, - end-of-life management and - product-line management.
Source	Sourcing and material acquisition and managing infrastructure.	• The - obtaining, - receiving, - inspecting, - holding and - issuing of material. • Monitor - sourcing quality, - in-bound freight, - component engineering, - vendor contracts and initiating vendor payments.
Make	Production execution	• Request and receive material. • Manufacture and test product. • Package, hold and/or release product. • Oversee - engineering changes, - facilities and equipment, - production status, - production quality, - shop scheduling/sequencing and - short-term capacity.
Deliver	Order management, warehouse management, and transportation and installation management	• Manage - channel business rules, - order rules deliver inventories and - deliver quality.

The REPAC model (*Figure 6*) focuses on the make process from the SCOR model. This model emphasizes the five fundamental business processes of a plant. The term REPAC is a concatenation of the first letter of each business process within the scope of this model (Heaton,1998:13).

- Ready
- Execute
- Process
- Analyze
- Coordinate as shown in *Figure 6*.

Each of these business processes are discussed in *Table 4*, on the following page.

Figure 6

The REPAC model

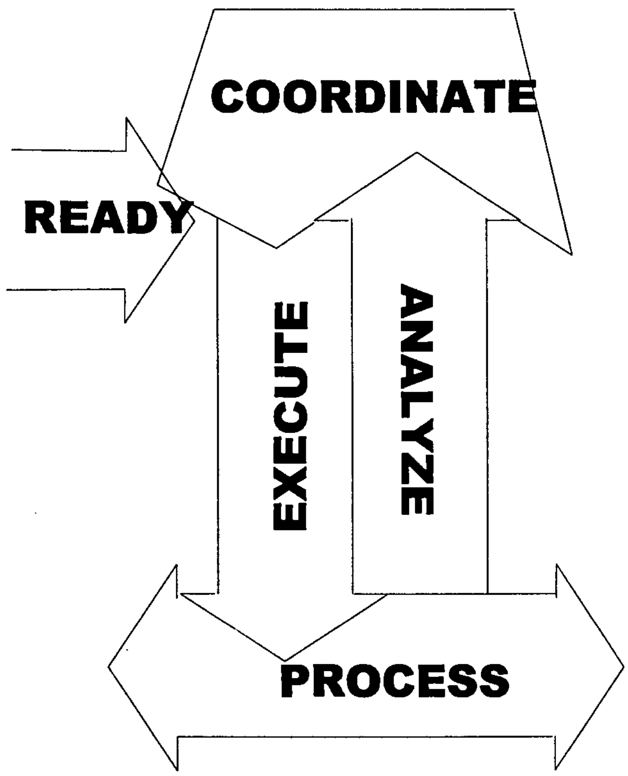


Table 4

Business Processes in the REPAC model

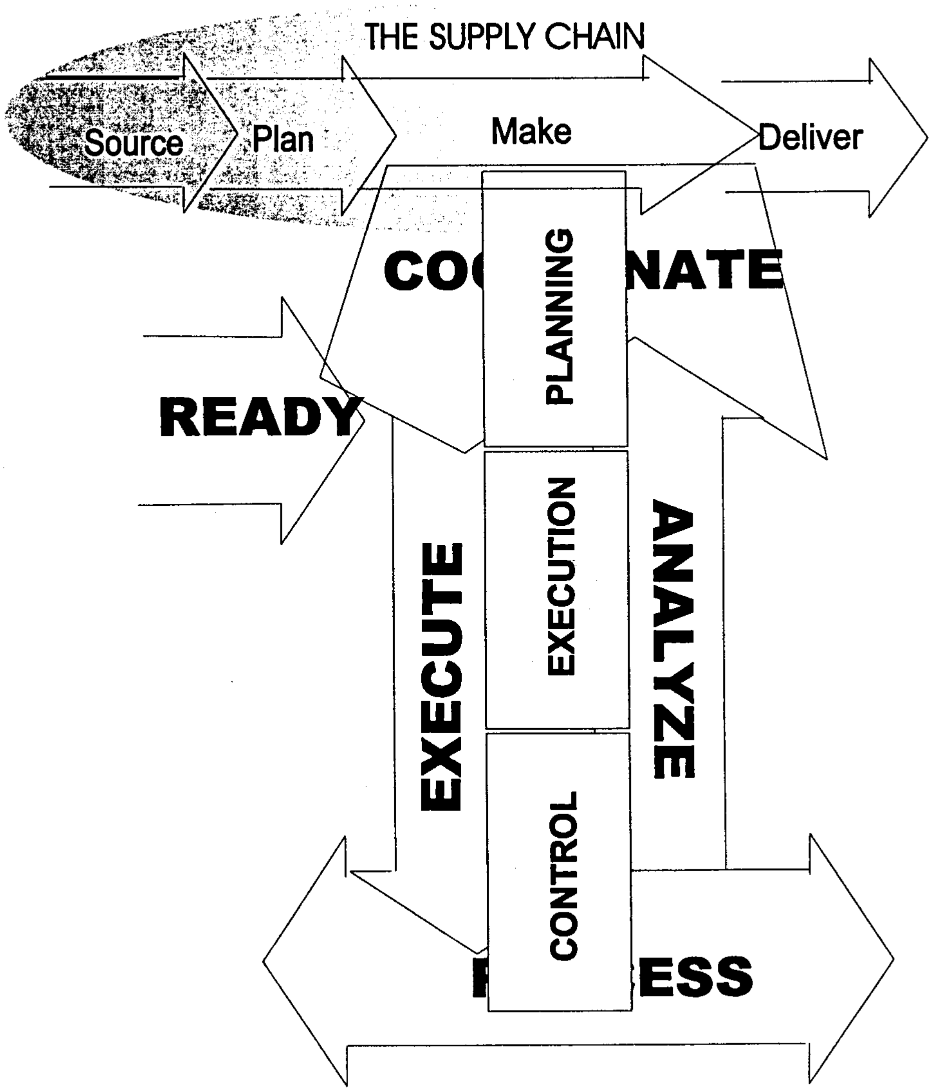
READY New Products for Production	With product lifecycles declining, plants must rapidly make new products ready for volume, high-yield production. This requires well controlled production processes, an automated, paperless process of new product introduction and engineering change, and integrated Quality Management.
EXECUTE Orders for Products	This process focuses on the execution of orders and processes. Similar to classic MES and WIP (Work-In-Process) Tracking, it manages the execution of a schedule within the plant, directing plant personnel, equipment, and recording actual progress.
PROCESS Capability Control and Management	This step corresponds to the existing process management and control infrastructure, including MMI (Man Machine Interface)/SCADA (Supervisory Control And Data Acquisition), PLC (Programmable Logic Controllers), DCS (Distributed Control Systems), and equipment with embedded controls. It focuses on the automation and control of Plant Systems. Process equipment is often expensive and complex, with sophisticated controls and extensive data collection.
ANALYZE Plant and Product Performance	This step focuses on identifying and using key performance information to further improve the process in a number of areas such as: quality and production improvement, calculating key performance indicators, summarizing data for supply chain planners, and assembling product information for downstream use. While plants may be a minor part of the overall supply chain, their models are complex with large volumes of data to manage.
COORDINATE the Plant Internally and With the Supply Chain	This final step is responsible for constantly updating the plant's schedule so everyone knows the best thing to be doing each time they start a new task. Since the plant is no longer isolated by inventory from the supply chain, a new mechanism is necessary to coordinate its operations. This process optimizes all of the activities in the plant, using status information from the *execute business process* and performance information from *analyze business process*. Coordination today is primarily an informal activity performed by managers with the odd finite scheduling application helping out.

The coordinate business process links with the supply chain, while the execute process links with MES. The relationship between MES and the supply chain is thus explained through a discussion of these two processes. This discussion is supported by *Figure 7*. This figure overlays AMR's original Three-Layer-Model, the REPAC model and a part of the SCOR model. The greatest overlap is with the execute and portions of the coordinate process arrows.

The business processes of the SCOR model as discussed in *Table 4* are also positioned on *Figure 7*, to show the integration between the coordinate process and the supply chain.

Figure 7

The REPAC model as link between the Three-Layer-Model and SCOR model



(a) COORDINATE : THE LINK WITH THE SUPPLY CHAIN

Swanton (1998:www.amrresearch.com/repac) explains that the integration with the supply chain is modeled through the *coordinate business process*:
"Since the plant is no longer isolated by inventory from the supply chain, a mechanism is necessary to coordinate its operations. This is primarily an informal activity performed by managers, with a finite scheduling application as support.
At its center the *coordinate process* is responsible for constantly updating the plant's schedule so everyone knows the best way to accomplish each new task. This process optimizes all of the activities in the plant, using status information from *the execute process* and performance information from the *analyze process*. These optimizations include the following:

- Exploding the high-level production requirements from the plan process into the detailed activities needed in the plant.
- Coordinating production with the actual status of incoming deliveries from suppliers arranged by the source process.
- Coordinating production with transportation in the deliver process.
- Sequencing operations in the plant to minimize cost while meeting external schedule commitments.
- Coordinating other plant activities including maintenance and engineering use of equipment."

(b) EXECUTE: THE RELATIONSHIP BETWEEN THE THREE LAYER MODEL AND THE REPAC MODEL

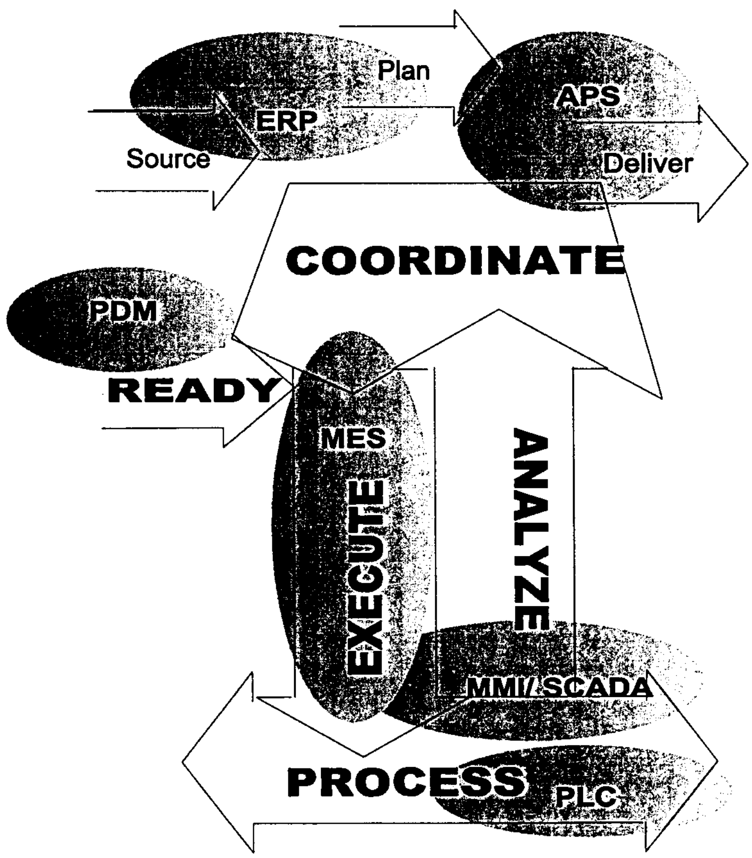
The relationship between the execute layer of the Three-Layer-Model and the REPAC model is explained as follow (Swanton,1998:www.amrresearch.com/repac/):

"Corresponding closely to classic MES and WIP tracking applications, the execute process manages the execution of a schedule within the plant. It communicates what needs to be done to the plant personnel and equipment, and it records what actually happens. Execute focuses on the transaction-processing portion of MES. It follows production and records any necessary data, including quality and abnormal condition information. Other workflow and reporting will be covered later, as transactional systems have proved incapable of meeting plant requirements in this area. The *execute process* is also simplified in that it does not try to optimize the execution itself; it uses a schedule created elsewhere (e.g., *the coordinate process*) and presents it to the operators.

2. 3.2. CONTEXTUALIZATION OF BUSINESS SYSTEMS

Figure 8 (Swanton, 1998: www.advmfg.com/repac) shows the coverage of the REPAC model in a typical enterprise architecture. Procurement (*Source*) and master planning (*Plan*) are handled by ERP while a demand-oriented APS handles distribution (*Deliver*) and coordinates factory schedules (*COORDINATE*). MES covers *EXECUTE* and PDM covers some but not all of the *READY* processes. MMI, PLC, and Computer Numerical Controls (CNCs) cover the *PROCESS*. Much of the rest, including all of *ANALYZE*, is not covered.

Figure 8
REPAC Model with centralized ERP/APS

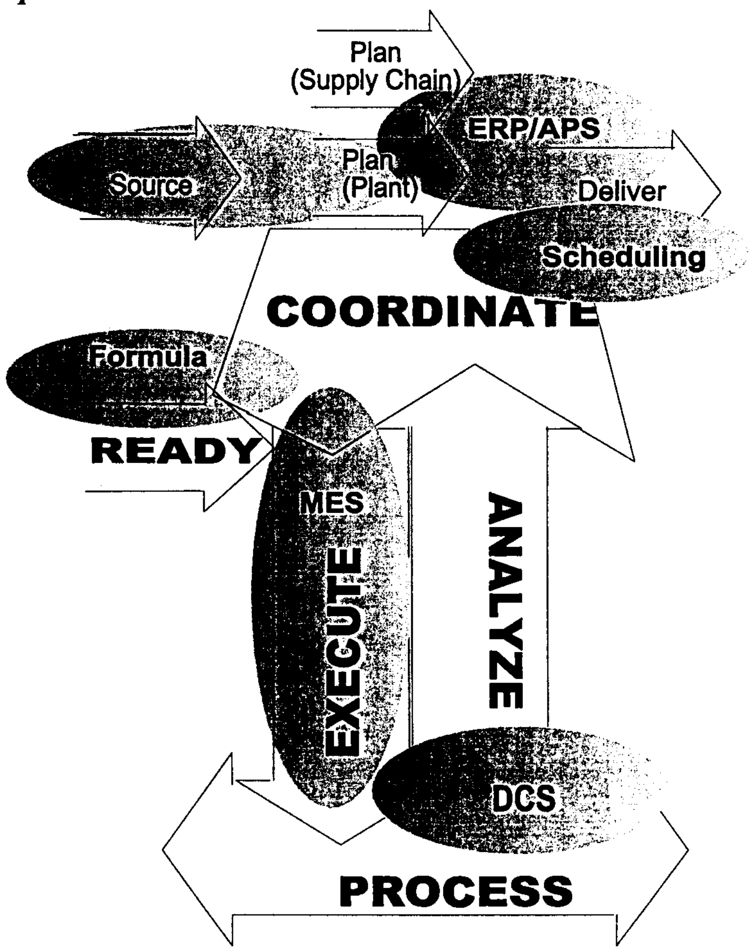


Origin (1999:2) makes the following comment in a marketing brochure:

"As Enterprise Resource Planning (ERP) and Control Systems vendors continue to expand their functionality to encompass that of MES, the MES layer is continuing to undergo changes. " The rest of the brochure is used to explain the a service provided by them to accomplish plant centric ERP.

Figure 9 (Swanton, 1998: www.advmfg.com/repac) shows an enterprise that has implemented ERP but that uses a plant-centric ERP to manage the batch process plant and sourcing of raw materials. A finite scheduling package sequences the batches, which are executed by an MES or batch execution package. The DCS handles the *PROCESS*. Again, much of the needed plant architecture is not covered by formal systems.

Figure 9
REPAC Model with plant centric ERP



2. 3.3. CONCLUSION

Hydrocarbon Online (1999: http://news.hydrocarbononline.com/info-tech/19980914-4955.html) concludes as follow on the REPAC explanation by Swanton:

"The key to this model, says Swanton, is that plant owners can choose what business systems occupy what parts of te overall process. A company with centralized ERP (that is, ERP being handled mainly at headquarters) could choose not to implement ERP at the plant level, and to keep planning and scheduling a corporate IT function. A company with "plant-centric ERP" could seek to integrate ERP modules on the plant floor, and to tightly link production and planning. 'Set an architectural direction for your plant,' Swanton advises, 'and then buy products on the basis of their fit with the architecture.' Swanton adds that this model guides the user to integrate various systems only as necessary to meet business goals.

Two other important issues are brought forward by the REPAC model:

1. There is great potential for the integration of MES with the supply chain and business models should reflect this.
2. MES business models and concepts are evolving at a high rate.

To achieve a better understanding of the second issue, the evolution of MES related concepts are investigated in the following chapter.